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Potato Spraying in Maine

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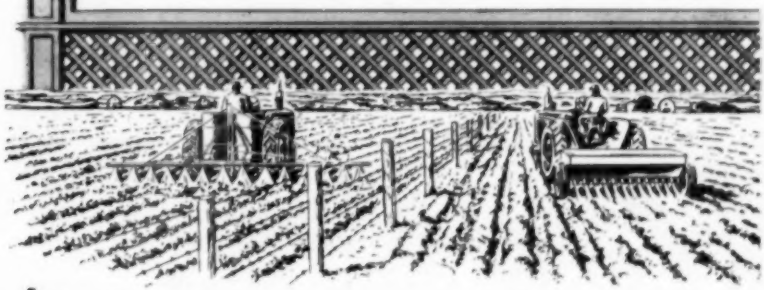

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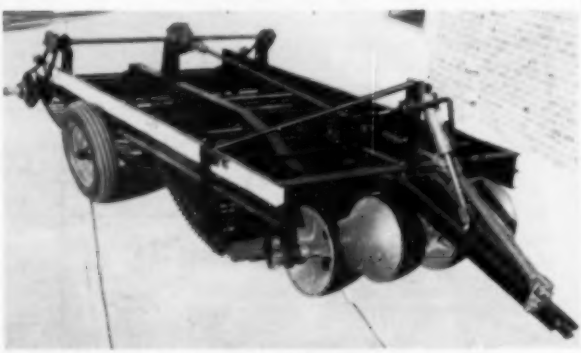

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OUR COVER PICTURE—*Control of late blight and insects is accomplished in Maine by weekly applications of pesticides. Many farmers use tractor-mounted sprayers such as is shown in the picture. Photo courtesy Maine Development Commission.*

# DISTRIBUTION OF PHYSIOLOGICAL RACES OF *PHYTOPHTHORA INFESTANS* (MONT.) DE BARY IN CANADA[1]

K. M. GRAHAM[2]

## INTRODUCTION

Late blight causes serious losses annually to potato and tomato crops in Canada. Good control of the disease is obtained by the timely application of fungicides, but the most effective means would be through the development of resistant varieties. In such a program knowledge of the distribution of the physiological races of the causal fungus, *Phytophthora infestans* (Mont.) de Bary is basic. To obtain this information, a nation-wide collection of diseased material was made in 1952 and 1953. The identification of the races represented in these and subsequent collections should provide comprehensive knowledge of the distribution of the races in Canada and of the fluctuations that may occur in the races of any given locality. This information will be of great significance to the program of potato and tomato breeding conducted by the Horticultural Division of the Experimental Farms Service. Furthermore, the adoption of the international system (1) for the designation of races by the use of differential genotypes makes possible the comparison of our results with those obtained in other countries.

## EXPERIMENTAL PROCEDURE AND RESULTS

Officers of the Plant Protection Division and of the Laboratories of Plant Pathology in the various provinces co-operated in sending to Ottawa during the harvest season collections of green tomato fruits and potato tubers showing the initial symptoms of late blight. The fungus was isolated from these specimens and cultured on 1.5 per cent oatmeal agar. At first, the cultures were maintained at room temperature and transferred to fresh media at frequent intervals. Under these conditions the fungus lost its virulence and its ability to sporulate. However, storage of the cultures at 13-15° C. favored sporulation, necessitated their transfer only once every six months, and made it possible to maintain them for as long as two years with only slight reduction in virulence. The procedure adopted was to test the mass isolates rather than single-zoospore cultures made from the mass isolates. The sole use of single-zoospore cultures might have resulted in the omission of races which might have been present in the lesions from which the original isolations were made.

The differential hosts were the tomato varieties Stokesdale and Geneva T-5, the potato variety Green Mountain and Black's (1) set of single-gene differentials representing the genes $R_1$, $R_2$, $R_3$, and $R_4$. The discovery of a single dominant factor for resistance to Race O in a strain of *Lycopersicum esculentum* Mill. var. *cerasiforme* (Dun.) A. Gray

[1]Accepted for publication March 3, 1955.
Contribution No. 1388 from the Botany and Plant Pathology Division, Science Service, Canada Department of Agriculture, Ottawa, Ontario, Canada.
[2]Associate Plant Pathologist, Botany and Plant Pathology Laboratory, Ottawa, Ontario, Canada.

designated as Geneva T-5 seems to justify the inclusion of this host among the differentials under the genotype "$R_1^t$". As no isolate was found which did not produce sporulating lesions on Stokesdale, it was assigned the genotype "$r^t$", to distinguish it from the genotype "r" of Green Mountain. The behavior of the type of resistance to Race O found in Geneva T-5 was studied in a series of crosses between Geneva T-5 and the susceptible variety Stokesdale. The pertinent data are recorded in table 1.

The potato differentials were grown from excised eyes in 4-inch pots to a height of approximately 6 inches and the tomatoes were grown to the stage of the fifth or sixth true leaf. As the potatoes grew more rapidly than the tomatoes, the latter had to be planted two weeks earlier so that the inoculations on both hosts could be performed concurrently. In order to test as large a number of isolates as possible at the same time, 25 compartments constructed of panes of greenhouse glass in a wooden frame were used as moist chambers and one pot of each of the 7 differentials was put in each compartment. A spore suspension of each mass isolate was prepared by washing the spores from two 10-day-old to 2-week-old cultures on oatmeal agar into 50 milliliters of distilled water. For the inoculation, a separate DeVilbiss atomizer was used for each isolate and only one compartment was opened at a time.

For a period of approximately 4 days, the chambers were maintained as closely as possible at a temperature of 65°-70°F., by shading and ventilating the greenhouse, and at a relative humidity of 100 per cent, by frequent sprayings within the chambers. At the end of this period, sporulation was usually evident on plants of susceptible differentials whereas necrotic lesions appeared on resistant ones. Unless the temperature dropped below 65°F., the test was not prolonged beyond the 4-day period. During the mid-winter months, however, six days were allowed before the final readings of the reactions were taken.

The differentials were scored as "+" or "—", indicating respectively the presence of spores on spreading lesions and the absence of spores on necrotic spots. Seventy isolates were then classified according to the international scheme recently adopted by Black, Mills, Mastenbroek and Peterson (1). When a given isolate sporulated on two or more differential hosts, a confirmatory test was made by inoculating, where possible, a host that combined the genes involved. From the reactions of the 70 isolates on the differential hosts it was possible to distinguish 8 physiological races. The reactions of the hosts to these races are given in table 2.

In conformation with the international system (1), the 8 races were designated according to the genotypes of the hosts they were capable of attacking. Therefore, the extension of the host range by the addition of the two tomato varieties permitted the differentiation of Race $1^t$, capable of sporulating on plants of the genotypes r, $r^t$ and $R_1^t$, and Race $1^t.4$, which attacks plants of the genotypes r, $r^t$, $R_1^t$ and $R_4$. The 70 isolates are grouped in table 3 according to the number that could be identified with known races or mixtures of races. Table 4 indicates the distribution of the races or mixtures of races by provinces.

The repeated occurrence of Race 4 among isolates from commercial varieties of potato and tomato carrying no resistance genes was surprising, because Race 0 had been expected. The presence of heavy sporulation

TABLE 1.—*Behavior of the gene $R_1^t$ in a series of crosses between Geneva T-5 ($R_1^t$) and Stokesdale ($r^t$)*

| Parentage | Number of Seedlings Resistant | Susceptible | Ratio Observed | Theoretical | Genotypes Involved |
|---|---|---|---|---|---|
| Geneva T-5 x Stokesdale | 57 | 0 | 1:0 | 1:0 | $R_1^t \times r^t$ |
| (GT-5 x St.) Selfed | 296 | 113 | 2.6:1 | 3:1 | $R_1^t r^t \times R_1^t r^t$ |
| (GT-5 x St.) x St. | 40 | 61 | 0.6:1 | 1:1 | $R_1^t r^t \times r^t$ |
| " " | 56 | 56 | 1:1 | 1:1 | " |
| " " | 46 | 56 | 0.8:1 | 1:1 | " |
| Geneva T-5 | 47 | 0 | 1:1 | 1:0 | $R_1^t$ |
| Stokesdale | 0 | 50 | 0:1 | 0:1 | $r^t$ |

TABLE 2.—*Reactions of differential hosts to 8 races of P. infestans.*

| Differential | Genotype | Reaction to Race 0 | $1^t$ | 1 | 1.2 | 1.4 | 4 | 1.2.4 | $1^t.4$ |
|---|---|---|---|---|---|---|---|---|---|
| *Tomato*: | | | | | | | | | |
| Stokesdale | $r^t$ | + | + | + | + | + | + | + | + |
| Geneva T-5 | $R_1^t$ | — | + | — | — | — | — | — | + |
| *Potato*: | | | | | | | | | |
| Green Mtn. | r | + | + | + | + | + | + | + | + |
| 835a(4) | $R_1$ | — | — | + | + | + | — | + | — |
| 1512c(16) | $R_2$ | — | — | — | + | — | — | + | — |
| Pentland Ace | $R_3$ | — | — | — | — | — | — | — | — |
| 1563c(14) | $R_4$ | — | — | — | — | + | + | + | + |
| 1647b(1) | $R_1R_2$ | — | — | — | + | — | — | + | — |
| 1506b(9) | $R_1R_4$ | — | — | — | — | + | — | + | — |
| 2070ab(3) | $R_2R_4$ | — | — | — | — | — | — | + | — |

+ Susceptible.
— Resistant.

TABLE 3.—*Classification of isolates.*

| Races | Isolates | Obtained from: | Genotype |
|---|---|---|---|
| 0 | 21 | Commercial varieties | r or $r^t$ |
| 4 | 24 | " " | r or $r^t$ |
| 0 + 4 | 11 | " " | r or $r^t$ |
| 1 | 6 | Canso, Keswick, Cherokee | $R_1$ (?) |
| 1.2 | 1 | Canso | $R_1$ (?) |
| 1.4 | 1 | Keswick | $R_1$ (?) |
| 1.2.4 | 3 | Keswick, Kennebec, Placid | $R_1$ (?) |
| $1^t$ | 1 | Geneva T-5 | $R_1^t$ |
| $1^t + 1^t.4$ | 2 | Snowflake, Rutgers | r or $r^t$ |

TABLE 4.—*Distribution of races of P. infestans in Canada.*

| Province | Number of Collections of Race: 0 | 4 | 0+4 | 1 | 1.2 | 1.4 | 1.2.4 | $1^v$ | $1+1^v.4$ |
|---|---|---|---|---|---|---|---|---|---|
| Newfoundland | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Prince Edward Island | 3 | 3 | 2 | 2 | 0 | 0 | 0 | 0 | 0 |
| Nova Scotia | 0 | 2 | 1 | 3 | 0 | 0 | 0 | 0 | 0 |
| New Brunswick | 0 | 2 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| Quebec | 4 | 15 | 3 | 1 | 1 | 1 | 2 | 0 | 0 |
| Ontario | 7 | 3 | 4 | 0 | 0 | 0 | 0 | 1 | 2 |
| Manitoba | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Saskatchewan | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Alberta | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| British Columbia | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |

on the differential host for Race 0, accompanied by one or two sporulating lesions on the leaves of the differential for Race 4, *within the same time interval* of 4 days following inoculation, led us to suspect the presence of mixtures of Races 0 and 4. When sporangia were collected from lesions on the differential for Race 4 and reinoculated on the same host, many more lesions appeared. Similarly, observations following inoculations with isolates of $1^v$ have led us to suspect that mixtures of $1^v$ and $1^v.4$ were present. We might then conclude that the "common race" of *P. infestans* is actually composed of Races 0 and 4, which may be isolated either alone or together.

In view of the relatively small number of collections, it is perhaps premature to draw any definite conclusions regarding the distribution of races. From table 4 it is apparent that the largest number of isolates of Race 4 originated in the province of Quebec. It cannot be concluded, however, that the same situation prevails in the other provinces, because more collections were received from Quebec than from any other. It is also interesting to note that Race 4 was collected either singly or in mixture from Manitoba and Saskatchewan where no resistant varieties have been grown on a commercial scale. This observation supports the conclusion that Race 4 is at least a part of the "common" race of *P. infestans*.

In an attempt to verify the suspicion that races were occurring in mixture, a 10-day-old culture of what appeared to be originally Race $1^v.4$ was selected and 100 single-zoospore cultures were obtained from it. For the isolation of the single-zoospore cultures, a suspension of sporangia was made in sterile water chilled to approximately 15° C. and then diluted by successively transferring drops of it from one tube to another of sterile water, until a "workable" concentration of sporangia was reached. No exact count of sporangia was made, but experience made possible a visual estimation of the turbidity of the suspension best suited for the deposit of sporangia sufficiently separated on an agar surface to permit isolation of emerged zoospores. The contents of the tube holding the final dilution of the suspension were poured over the surface of 1.5 per cent oat extract agar in Petri dishes. This extract was prepared by soaking 200 grams of Quaker Rolled Oats in 500 milliliters of water for 24 hours and filtering the supernatant liquid through coarse filter paper until fairly

clear. This was added to 15 grams of agar dissolved in 500 milliliters of water, made up to 1 liter, and sterilized. Later, it was found that the addition of about 5 grams of sucrose to 1 liter of the above medium favored the growth of the germ tubes. The Petri dishes containing oat extract agar, after being flooded with a suspension of sporangia, were placed at 15°C. overnight. The lower temperature favored the emergence of zoospores and subsequent germination The water was then poured off, and the dishes were inverted to permit the surface of the medium to dry. After 3 hours, they were examined with a dissecting microscope (25X). The germinated zoospores could be distinguished from germinated sporangia by their much smaller size, and spherical rather than elliptical shape. They were then picked off on a disc of agar and transferred singly to marked areas in Petri dishes containing 1.5 per cent oat extract agar. After 3 to 5 days at 15°C., the growth from the individual zoospores could be distinguished with the naked eye and subcultures were made on slants of oatmeal agar.

The 100 single-zoospore cultures so obtained were tested separately on a host range composed of plants of genotypes r, $r^t$, $R_1{}^t$, $R_1$, $R_2$ and $R_3$. Unfortunately, the differential bearing the genotype $R_4$ had to be omitted because sprouted tubers were not available. Ninety-six of these cultures produced identical reactions on the hosts used, but the remaining 4 had apparently lost their ability to sporulate on any of the hosts. The superficial flecks which formed on r, $r^t$ and $R_1{}^t$ failed to spread and sporulate even after 8 days in the inoculation chamber. Indeed, these 4 nonsporulating, avirulent cultures typified the trend of many of the isolates which we have attempted to maintain for long periods of time on oatmeal agar, under conditions of frequent transfer.

## Discussion

The suggestion is offered that the mycelium of *P. infestans*, as it grows in its natural hosts is heterokaryotic. Nuclei of the common race O may predominate in the mycelium in lesions on hosts carrying no genes for resistance. There may be a selective factor in the host which favors the multiplication of nuclei of the common race. If the fungus is transferred to a purely saprophytic medium, this selective factor of the host cannot operate and the nuclei of any other race or races that may be present are probably permitted to multiply. It may be possible, however, that the culture medium also exerts a selective influence with the result that the race best suited to the medium may eventually predominate. It is further suggested that the avirulent type arises from nuclei that are "carried" in part of the mycelium of the common race. The sterile growth is apparently well adapted to some factor provided by the culture medium which may exert a selective influence on that component and favors its multiplication at the expense of the more virulent types.

If one accepts the concept of a state of nuclear heterogeneity, or heterokaryosis in the pathogen, it becomes increasingly imperative to isolate and maintain cultures which are genetically pure. The zoospores of *P. infestans* were found to be uninucleate (2) and ought therefore to be used for the establishment of such pure lines of physiological races. Consequently, single-zoospore cultures of Races 0, 1, 4, 1.4, $1^t$ and 1.2.4 have been isolated. To date, the culture of Race O has been maintained

on artificial media for two years without showing a change in host relationships. Furthermore, single-zoospore cultures of Races 1 and 1.2.4 have not yet shown a change in their ability to attack their appropriate hosts.

It must be emphasized, however, that the mere establishment of a pure line of a given race will probably not prevent it from mutating during continuous growth on either artificial media or on host tissue. However, its initial purity having been established, much may be learned about its possible rate of mutation and the response of the mutants to various selective factors.

## Summary

A gene conferring resistance to Race 0 of *Phytophthora infestans* was found in a strain of *L. esculentum* var. *cerasiforme*. In crosses with the susceptible tomato variety Stokesdale, this gene was found to behave as a simple dominant. The resistant tomato, Geneva T-5, was therefore assigned the genotype $R_1^t$ and included in the series of hosts used to differentiate physiological races of *P. infestans*. Stokesdale was included under the genotype $r^s$.

Seventy isolates of *P. infestans*, obtained from material collected in 9 provinces of Canada during 1952 and 1953, were grouped into 8 races, including 0, $1^t$, 1, 1.2, 1.4, 4, 1.2.4 and $1^t.4$.

Eleven of the 70 isolates were apparently mixtures of Races 0 and 4, and two isolates seemed to be mixtures of Races $1^t$ and $1^t.4$. Races 0 and 4 were obtained from commercial varieties of potato and tomato lacking genes for resistance. Races 1, 1.2, 1.4 and 1.2.4 were isolated from the potato varieties Canso, Keswick, Kennebec and Placid, which presumably possess one or more resistance genes. Races $1^t$ and $1^t.4$ occurred on Geneva T-5, the tomato variety Rutgers, and the potato variety Snowflake. It was concluded that the so-called common race of *P. infestans* is actually composed of Races 0 and 4.

The suggestion is offered that *Phytophthora infestans* is heterokaryotic and that both the natural hosts and artificial culture media may exert selective influences upon components of the common race.

Pure lines of several races have been maintained with their original virulence for a considerable period of time on oatmeal agar, after they were isolated from single zoospores.

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2. Graham, K. M. 1954. Nuclear behavior in *Phytophthora infestans* (Mont.) de Bary. (Abst.) Phytopath. 44: 490.

## Acknowledgments

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# APPLICATION OF CERTAIN HORMONES TO PREVENT FLOWER ABSCISSION IN TWO POTATO *(SOLANUM TUBEROSUM)* VARIETIES[1]

MOHAMED ASLAM ZAFAR[2]

To carry out an effective hybridization program in potato *(Solanum tuberosum)* breeding, the presence of a flower is essential as in other crops and it must have functional parts, *i.e.*, male and female. Even if one of these parts is sterile the other can still be used as a parent. In some varieties of potatoes, however, abscission of flower buds takes place, making it impossible to use them as parent plants. The abscission has been overcome at times by girdling the stem and also by growing the plant in a nutrient solution (McLean and Stevenson 2). Many workers have obtained good flowering and seed set in potatoes by increasing the day length by artificial light.

In potatoes Clarke, Edmundson and Lombard (1) studied the effect, on the reduction of bud and flower drop, of spraying a-naphthaleneacetamide on the plants. They used the Sebago and Irish Cobbler and the seedling S 245-25. Results indicate that a-naphthaleneacetamide was not effective in reducing bud and flower drop in these three sorts and with higher concentrations the number of flowers were actually reduced. Oniscenko (3) at the Ukrainian Scientific Research Institute of vegetable growing improved the fruit set of potatoes by treatment with 0.01 per cent of a 2,4-dichlorophenoxy-p-butyric acid. Appreciable increase in seed setting was also obtained in the crosses of Ella x Katahdin. In some of his crosses Swaminathan (5) used an aqueous solution of a-naphthaleneacetic acid to prevent the flower from falling.

In an experiment with the potato variety Bintje, Wiersema (8) demonstrated an increased seed set by hormone application. This potato variety had produced no viable pollen and few fertile eggs so that when it was pollinated very few egg cells were fertilized, resulting in an insufficient supply of some growth substance which apparently is necessary to prevent abscission or abortion. An experiment was set up using 0.1 and 0.2 per cent 2,4,-dichlorophenoxyacetic acid spray on the flowers at different intervals after pollination. In summarizing his results, he said that the 0.2 per cent solution sprayed on the plants two to three days after pollination produced a very good set of berries and seed.

The results of almost all experiments show an improvement by using plant hormones, in reducing flower and fruit abscission and in producing a higher percentage of fruit and subsequent seed set in cases where no sterility is involved. These demonstrate that the use of hormones is warranted by breeders facing similar problems. They also demonstrate that the method itself is not a cure-all nor will any one compound be successful in all cases. Only experimentation can show which compound or mixture might prove useful for a certain crop or even for a certain

[1]Accepted for publication February 3, 1955.
Paper No. 315, Department of Plant Breeding, Cornell University, Ithaca, N. Y. The paper is a condensation of a thesis presented to Cornell University, in partial fulfillment of the requirements for the M.S. degree, by Mohamed Zafar, now returned to Lyallpur, Pakistan. The condensation was prepared by Dr. J. R. Livermore of the Department of Plant Breeding at Cornell University, Ithaca, N. Y.

[2]Punjab Agriculture College, Lyallpur, Pakistan.

variety of a crop. Increased experimentation with different hormones and concentrations should prove their value. Their use will always be limited but justifiable.

The objective of the experiment reported in this paper was to improve the flowering and fruit set by preventing the formation of an abscission layer. Two varieties of potato, Russet Burbank and Canoga, were used. In Russet Burbank the flower buds generally drop before the flowers open, whereas in Canoga sometimes the flowers open and berries are obtained, while at other times the flower buds drop.

Seven hormones were used in this research.

| Hormone | Abbreviations |
|---|---|
| 1. 2,4- Dichlorophenoxyacetic acid | 2,4-D |
| 2. 2,4,5 Trichlorophenoxyacetic acid | 2,4,5 - TCPA |
| 3. a-2, 4,5 Trichlorophenoxyacetic propionic acid | 2,4,5 - TCPP |
| 4. p-Chlorophenoxyacetic acid | pCPA |
| 5. a-Napthaleneacetic acid | NAA |
| 6. Indolebutyric acid | IBA |
| 7. O-Chlorophenoxyacetic acid | O-CPA |

A preliminary experiment was conducted in November 1953 in order to ascertain the suitable concentration. In this preliminary test 25 p.p.m. and 100 p.p.m. were tried and since 25 p.p.m. proved to be better it was chosen for the main experiment.

In February 1954 the main experiment was started. A 25 p.p.m. aqueous solution of each of the seven chemicals was made with distilled water. Unlike Wiersema (8) and Swaminathan (5) the writer tried hormones at different stages of plant growth. Tubers of both varieties were allowed to sprout before planting. The stages at which the treatments were given are as follows:

1. Tuber Stage — The tubers were sprayed and then planted.
2. Four-inch Stage — When plants were about four inches tall; whole plant sprayed.
3. Fully Grown Plant — Just before buds had appeared, whole plant sprayed.
4. Bud Stage — When buds had appeared, the buds only were sprayed.

Tubers were planted in standard six-inch pots. For each variety there were two replications at each stage and for each hormone. Only two clusters of flowers were used in each replicate. Two pots received no treatment to serve as check plants in each variety. Seedling 9V 224-3, a good pollinator, was used for all pollination purposes.

After planting, the pots of each variety were randomized within the variety for treatments at different stages. Complete randomization could not be used because of the fact that the Canoga grew much more quickly than the Russet Burbank and Canoga plants are bushy and vigorous. Because of limited space the pots had to be placed close to each other. So if Russet Burbank had been randomized with Canoga plants the latter plants would have affected Russet Burbank's growth adversely.

As soon as the plants began to grow, 16-hour day length was provided

by artificial light. A movable wooden frame with eight 150 watt electric bulbs was hung above the bench.

As the plants reached the stages at which they were to be treated, they were removed from the bench and taken outside so that the hormone would not effect other plants. After treatment, the plants were not put back until the spray had dried and there was no smell of hormone from the plant. It usually took 20 to 30 minutes for the spray to dry on the plant.

The flowers which opened as a result of hormone application were pollinated between 7 and 10 o'clock in the morning. Berries which were formed were collected later. The seeds were counted and the averages appear in tables 1 and 2. A summary of the data expressed in percentages is given in table 3.

The data were transformed into angles (Snedecor 4) and the Analysis of Variance was calculated.

To judge the best stages and treatments the method proposed by Tukey (1953), which is called *hsd* (honestly significant difference), was used. The *hsd* was calculated for stages and treatments. These results are recorded in table 4.

## Flowers Opened — Canoga

Looking at the results in table 4 it is apparent that there is a highly significant difference among stages and treatments. The spraying of hormones on fully grown plants gave significantly better results than did the spraying at tuber stage, and all the hormones proved superior to the check.

NAA was significantly superior to the check and 2,4,-D, p-CPA and O-CPA were not quite so effective as NAA but were better than the check. (Figure 1)

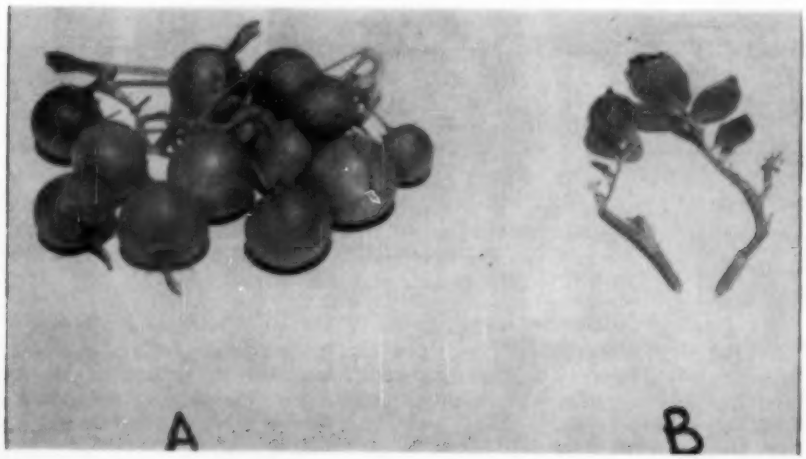


Figure 1.—A Fruit set on fully-grown plant treated with a-Naphthaleneacetic acid. B. Inflorescences, from which buds have dropped, on fully-grown plant without treatment.

TABLE 1.—*The effect of hormone spray applied at four stages of growth on the flower, fruit, and seed set in the two varieties. (Variety - Canoga.)*

| Hormone | Stage | Mean of Two Replications | | | | |
|---|---|---|---|---|---|---|
| | | Buds Appeared | Buds Dropped | Flowers Pollinated | Fruit Set | Seed per Fruit |
| 2,4-D | 1 | 27.0 | 18.0 | 9.0 | 4.5 | 95.0 |
| | 2 | 24.5 | 7.0 | 10.5 | 6.0 | 96.0 |
| | 3 | 30.0 | 0.0 | 20.0 | 17.5 | 87.0 |
| | 4 | 20.5 | 9.5 | 11.0 | 8.0 | 71.5 |
| 2,4,5-TCPA | 1 | 24.5 | 17.0 | 7.5 | 5.0 | 84.0 |
| | 2 | 29.0 | 0.0 | 20.0 | 14.5 | 98.5 |
| | 3 | 29.0 | 0.0 | 20.0 | 16.5 | 97.5 |
| | 4 | 24.5 | 10.0 | 14.5 | 6.5 | 63.5 |
| 2,4,5-TCPP | 1 | 24.5 | 13.5 | 11.0 | 7.0 | 85.5 |
| | 2 | 24.0 | 4.0 | 17.0 | 13.0 | 96.0 |
| | 3 | 28.0 | 0.0 | 20.0 | 16.0 | 73.5 |
| | 4 | 22.5 | 9.0 | 13.5 | 10.0 | 62.5 |
| p-CPA | 1 | 19.5 | 8.5 | 11.0 | 8.0 | 94.0 |
| | 2 | 28.0 | 0.0 | 20.0 | 10.0 | 54.5 |
| | 3 | 27.0 | 0.0 | 20.0 | 15.5 | 94.0 |
| | 4 | 27.5 | 0.0 | 20.0 | 16.5 | 85.0 |
| NAA | 1 | 22.0 | 0.0 | 20.0 | 14.0 | 79.5 |
| | 2 | 29.0 | 0.0 | 20.0 | 9.0 | 94.0 |
| | 3 | 25.0 | 6.0 | 15.5 | 11.5 | 95.0 |
| | 4 | 28.0 | 0.0 | 20.0 | 17.0 | 91.0 |
| IBA | 1 | 20.0 | 9.0 | 9.5 | 6.5 | 46.0 |
| | 2 | 21.0 | 3.5 | 13.5 | 11.5 | 67.5 |
| | 3 | 23.5 | 0.0 | 20.0 | 17.0 | 86.0 |
| | 4 | 18.0 | 6.0 | 12.0 | 4.5 | 85.0 |
| O-CPA | 1 | 24.5 | 3.5 | 16.5 | 14.5 | 95.0 |
| | 2 | 26.0 | 0.0 | 20.0 | 15.0 | 90.5 |
| | 3 | 27.5 | 0.0 | 20.0 | 10.0 | 94.5 |
| | 4 | 21.0 | 7.5 | 13.5 | 7.5 | 58.5 |
| Check | | 19.5 | 16.5 | 3.0 | 1.5 | 46.5 |

### FRUIT SET — CANOGA

The results indicate that there is a highly significant difference between treatments but that no stage proved better than any other.

2,4,5-TCPP has given the best results followed by p-CPA, O-CPA, 2,4,5-TCPA, NAA, 2,4-D and indolebutyric acid.

### FLOWERS OPENED — RUSSET BURBANK

The results reveal that there is a highly significant difference among stage and treatments. The four-inch stage has shown significant superiority to be better than the other stages, though the difference is not mathematically significant.

Indolebutyric acid was found to be most significantly superior when compared with the check p-CPA, O-CPA, 2,4-D, 2,4,5-TCPA and NAA also prevented the formation of the abscission layer and plants subjected to these treatments developed more flowers than the check plants.

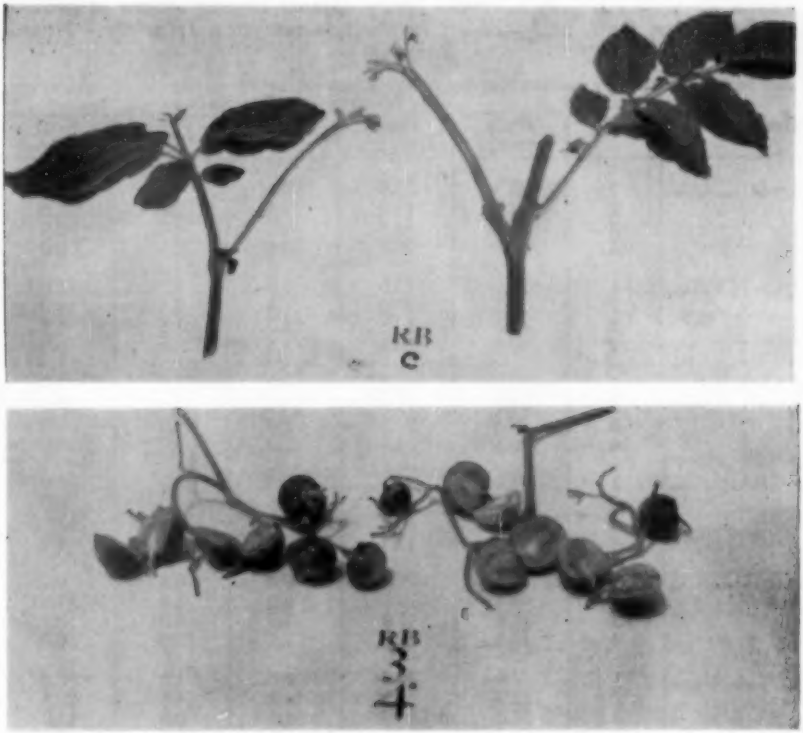


FIGURE 2.—Upper - Inflorescences, from which buds have dropped on four-inch-stage plant without treatment.

Lower - Fruits, with seeds, on four-inch-stage plant treated with a-2,4,5 Trichlorophenoxy-propionic acid.

## FRUIT SET — RUSSET BURBANK

The analysis of variance showed that there is a highly significant difference among stages and treatments and there is also a highly significant interaction between stages and treatments. No stage could be shown to be statistically significantly different when subjected to the *hsd* test but the four-inch stage (Table 2) has maintained an apparent superiority, and, to a lesser extent, the fully-grown-plant stage appeared better than the others.

Here also the lasting effect of the hormone is valuable, as flowers which opened were pollinated and seed balls with seed were obtained. The 2,4-D has shown overall superiority compared with the check and 2,4,5-TCPA. Indolebutyric acid is next best in performance. Considering only the four-inch stage which is, in general, superior, most of the seed balls with seed have been obtained by the application of 2,4,5-TCPP and NAA. Indolebutyric acid is third in effectiveness.

TABLE 2.—*The effect of hormone spray applied at four stages of growth on the flower, fruit, and seed set in the two varieties. (Variety - Russet Burbank.)*

| Hormone | Stage | Mean of Two Replications | | | | |
|---|---|---|---|---|---|---|
| | | Buds Appeared | Buds Dropped | Flowers Pollinated | Fruit Set | Seed per Fruit |
| 2,4-D | 1 | 27.5 | 18.5 | 9.0 | 0.5 | No seed |
| | 2 | 22.5 | 13.0 | 9.5 | 2.0 | 32.5 |
| | 3 | 20.0 | 18.5 | 1.5 | 0.0 | 0.0 |
| | 4 | 29.5 | 26.5 | 3.0 | 2.0 | 2.0 |
| 2,4,5-TCPA | 1 | 26.0 | 22.0 | 4.0 | 0.0 | 0.0 |
| | 2 | 26.5 | 12.0 | 14.5 | 0.0 | 0.0 |
| | 3 | 23.5 | 18.5 | 5.0 | 1.5 | 1.5 |
| | 4 | 17.5 | 16.0 | 1.5 | 0.0 | 0.0 |
| 2,4,5-TCPP | 1 | 29.5 | 21.5 | 8.0 | 1.5 | 4.5 |
| | 2 | 25.5 | 11.0 | 14.5 | 8.0 | 14.0 |
| | 3 | 22.5 | 22.5 | 0.0 | 0.0 | 0.0 |
| | 4 | 25.5 | 25.5 | 0.0 | 0.0 | 0.0 |
| p-CPA | 1 | 35.0 | 22.5 | 12.5 | 0.0 | 0.0 |
| | 2 | 20.0 | 13.5 | 6.5 | 0.0 | 0.0 |
| | 3 | 28.5 | 16.5 | 12.0 | 2.0 | 10.5 |
| | 4 | 19.5 | 15.0 | 4.5 | 1.0 | 4.0 |
| NAA | 1 | 27.5 | 21.5 | 6.0 | 0.0 | 0.0 |
| | 2 | 28.5 | 19.5 | 9.0 | 5.0 | 38.5 |
| | 3 | 18.5 | 17.0 | 1.5 | 0.0 | 0.0 |
| | 4 | 18.5 | 17.5 | 1.0 | 0.0 | 0.0 |
| IBA | 1 | 27.0 | 19.0 | 8.0 | 1.0 | 3.0 |
| | 2 | 23.0 | 13.0 | 10.0 | 4.5 | 29.5 |
| | 3 | 24.0 | 13.0 | 11.0 | 0.5 | 11.0 |
| | 4 | 24.5 | 15.0 | 9.5 | 1.5 | 3.5 |
| O-CPA | 1 | 26.5 | 20.0 | 6.5 | 1.0 | 19.5 |
| | 2 | 19.0 | 13.5 | 5.5 | 1.5 | 3.0 |
| | 3 | 24.0 | 9.5 | 14.5 | 2.0 | 29.0 |
| | 4 | 25.0 | 23.0 | 2.0 | 0.0 | 0.0 |
| Check | | 22.0 | 22.0 | 0.0 | 0.0 | 0.0 |

## DISCUSSION

The results of this experiment indicate that hormones do affect the formation of an abscission layer and inhibit or delay the flower fall. These findings are in accordance with the reports of previous workers.

This author has found that the time of application is very important and that varieties respond differently to the several hormones. Canoga and Russet Burbank did not behave the same in regard to the time of application nor in their response to the various hormones in this experiment.

When fully grown plants (before the flower buds had appeared) of Canoga were sprayed with different hormones, they developed a significantly better flower set than those sprayed at any other stage.

TABLE 3.—*A summary of data on flowers opened and fruit set at different growth stages in two varieties of potatoes.*

| Treatment | | Stages | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Tuber | | 4-inch | | Fully Grown Plant | | Bud | |
| | | Flowers Opened As Per cent of Buds Appeared | Fruit Set as Per cent of Flowers Pollinated | Flowers Opened As Per cent of Buds Appeared | Fruit Set as Per cent of Flowers Pollinated | Flowers Opened As Per cent of Buds Appeared | Fruit Set as Per cent of Flowers Pollinated | Flowers Opened As Per cent of Buds Appeared | Fruit Set as Per cent of Flowers Pollinated |
| 2,4-D | Canoga | 33.33 | 50.00 | 57.14 | 57.14 | 100.00 | 87.50 | 53.66 | 72.73 |
| | Burbank | 32.73 | 5.56 | 42.22 | 21.05 | 7.50 | 0.00 | 10.17 | 66.67 |
| 2,4,5-TCPA | Canoga | 30.61 | 66.67 | 100.00 | 72.50 | 100.00 | 82.50 | 59.18 | 44.83 |
| | Burbank | 15.38 | 0.00 | 54.72 | 0.00 | 21.28 | 30.00 | 8.57 | 0.00 |
| 2,4,5-TCPP | Canoga | 44.90 | 63.64 | 83.33 | 76.47 | 100.00 | 80.00 | 60.00 | 74.07 |
| | Burbank | 27.11 | 18.75 | 56.86 | 55.17 | 0.00 | 0.00 | 0.00 | 0.00 |
| p-CPA | Canoga | 56.41 | 72.73 | 100.00 | 50.00 | 100.00 | 77.50 | 100.00 | 82.50 |
| | Burbank | 35.71 | 0.00 | 32.50 | 0.00 | 42.11 | 16.67 | 23.08 | 22.22 |
| NAA | Canoga | 100.00 | 70.00 | 100.00 | 45.00 | 76.00 | 74.19 | 100.00 | 85.00 |
| | Burbank | 21.82 | 0.00 | 31.58 | 55.56 | 8.11 | 0.00 | 5.41 | 0.00 |
| IBA | Canoga | 55.00 | 68.42 | 83.33 | 85.19 | 100.00 | 85.00 | 66.67 | 37.50 |
| | Burbank | 29.63 | 12.50 | 43.48 | 45.00 | 45.83 | 4.55 | 38.78 | 15.79 |
| O-CPA | Canoga | 85.71 | 87.88 | 100.00 | 75.00 | 100.00 | 50.00 | 64.29 | 55.56 |
| | Burbank | 24.53 | 15.38 | 28.95 | 27.27 | 60.42 | 13.79 | 8.00 | 0.00 |
| Check | (Canoga) | 15.38 | 50.00 | 50.00 | 50.00 | 50.00 | 50.00 | 50.00 | 50.00 |
| Check | (Burbank) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

TABLE 4.—*Analysis of variance for total number of flower buds appeared and flowers opened. (Variety - Canoga.)*[1]

| Source of Variation | D.F. | Sum of Squares | Mean Square | F |
|---|---|---|---|---|
| Total | 63 | 51927.4379 | | |
| Replications | 1 | 1798.8201 | 1798.8201 | |
| Stages | 3 | 8478.3068 | 2826.1023 | 10.33** |
| Treatments | 7 | 24622.9898 | 3517.5700 | 12.85** |
| Stages x Treatments | 21 | 8543.8121 | 406.8482 | 1.49 |
| Error | 31 | 8483.5091 | 273.6616 | |

**Highly significant at 1 per cent level.

hsd (Honestly significant difference)

For Stages

hsd .05 = 22.41

Per cent = <

$\bar{x}_4 - \bar{x}_1 = 29.33$ 24.0

For Treatments

| hsd .05 = 26.85 | Per cent = < |
|---|---|
| $\bar{x}_5 - \bar{x}_8 = 65.19$ | 82.4 |
| $\bar{x}_3 - \bar{x}_1 = 28.83$ | 23.3 |
| $\bar{x}_6 - \bar{x}_8 = 60.62$ | 75.9 |
| $\bar{x}_7 - \bar{x}_8 = 57.29$ | 70.8 |
| $\bar{x}_2 - \bar{x}_8 = 47.13$ | 53.7 |
| $\bar{x}_6 - \bar{x}_8 = 47.11$ | 53.7 |
| $\bar{x}_3 - \bar{x}_8 = 44.56$ | 49.2 |
| $\bar{x}_1 - \bar{x}_8 = 36.36$ | 35.2 |

[1]In order to save space and printing costs three other tables, similar in form to table 4, have been omitted. They had to do with the relationship between 'flowers pollinated and seed balls obtained,' variety Canoga; and 'number of flower buds appeared and flowers opened,' and 'flowers pollinated and seed balls obtained,' variety Russet Burbank. However, Mr. Zafar made use of the statistical information from those tables in his discussion. (J. R. Livermore)

Overall performances of NAA are significantly superior to the check and 2,4-D. All other hormones have given significantly better performance than the check. Perhaps this is due to the fact that the Canoga variety does bloom occasionally, and sometimes fruits develop, so a slight hormone supply will help in inhibiting or delaying formation of the abscission layer.

The 2,4,5-TCPP treated plants gave significantly better fruit set than the check, followed closely by p-CPA, O-CPA, 2,4,5-TCPA, NAA and 2,4-D. It is apparent that 2,4,5-TCPP may have more lasting effect but the difference is not very great.

In Russet Burbank, on the other hand, hormone application at the

four-inch stage proved significantly superior for flower set, relative to the bud stage. Though the four-inch stage is not significantly better than the tuber and the fully-grown plant stage, still the difference is noticeable. Among the chemicals indolebutyric acid gave significantly better flower set than the check, followed by p-CPA, O-CPA, 2,4-D, 2,4,5-TCPA and NAA.

When the flowers which had opened were pollinated and seed balls obtained, 2,4-D was significantly superior to the check and 2,4,5-TCPA, followed by indolebutyric acid. Here again 2,4-D has a more lasting effect on this variety. Though this chemical was not the best to induce flowering, it certainly gave the greatest number of seed balls in all stages.

It may be argued that initiation of flowering primordia takes place at different stages of plant growth in various varieties and that this initiation is affected by the hormone. If, at any time, the deficiency of hormones is removed by the application of synthetic hormones then the abscission layer may possibly be inhibited or delayed in later stages.

The time of application is very important. This view is strengthened by the fact that in the greenhouse, while the experiment was in progress, certain hormones were applied on the flower buds of Russet Burbank plants that were being used by Dr. J. R. Livermore for breeding purposes. Those flower buds fell off after two or three days but the next cluster of flowers, two or three weeks later, opened well.

## Summary

Investigations were undertaken to obtain flowers and fruit set in two potato varieties, namely, Canoga and Russet Burbank. Almost always in Russet Burbank, and quite often in Canoga, the flower buds drop. Seven hormones were used and a 25 p.p.m. aqueous solution of each was prepared. Potato plants were sprayed with hormones at different stages of plant development. These stages were; seed tuber stage, four-inch stage, fully grown plant stage, and flower bud stage.

The results indicate that in the Canoga variety, flowers and fruit were obtained when the plants were sprayed with any of the above-mentioned hormones at any stage, but the fully-grown-plant stage proved to be better for hormone treatment since it affects flower development. At this stage the best flowering and fruit set were obtained by the application of 2,4-D followed by IBA, 2,4,5-TCPA, and 2,4,5-TCPP.

In the case of Russet Burbank more selectivity as to stage of plant growth and type of hormone was required to obtain good flowering and fruit set. The four-inch stage proved to be better and at this stage the application of NAA and 2,4,5-TCPP gave the best results with IBA as third choice.

These results were obtained from a single experiment. In order to make definite recommendations much more research will have to be conducted.

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[3]In his thesis Mr. Zafar cited approximately twenty-five references. Only those referred to in this condensed version have been included in the literature cited.

# NATURAL DEHYDRATION OF CULL POTATOES BY ALTERNATE FREEZING AND THAWING[1]

R. H. TREADWAY,[2] E. G. HEISLER,[2] R. T. WHITTENBERGER,[2]
M. E. HIGHLANDS[3] AND J. S. GETCHELL[3]

Drying of potatoes by alternate freezing and thawing was apparently originated nearly 2,000 years ago by inhabitants of the highland country of western South America. (5) Archeological proof is available in the existence of ornamental pots shaped in the form of dehydrated potatoes and in the recovery of dried potatoes that are well preserved after many centuries. Pots unearthed in the northern, coastal area of Peru are believed to date back to approximately 200 A.D. Dried potatoes are frequently found in the pre-Columbian graves of the arid coastal zone.

In dehydrating these potatoes, tubers were spread on the ground of high plateaus where they froze during the night and thawed during the day. Much of the juice was lost during the thaws. After four or five days of freezing and thawing, the natives trampled on the potatoes to expel most of the remaining juice. Following this treatment, the potatoes were left 15 to 20 days longer to undergo further dehydration by action of sunlight and frosts. This product, called *chuño*, consisted of hard, dark, shrivelled potatoes that had been greatly reduced in volume and weight as a result of natural dehydration. It was used, as such, for animal feed.

For food use, preparation of the dehydrated potatoes was modified to give a nearly white product called *tunta* or "moray." After partial dehydration by freezing and thawing, the potatoes were placed in a pool or stream of cold water and allowed to remain for one to two months. They were then dried in the sun about one week. Extraction of the dark substances gave an attractive product that could be ground into flour for baking or reconstituted in water to be cooked and served in various forms instead of fresh potatoes. Preparation of *chuño* and *tunta* continue up to the present time in the plateau region of western South America.

This dehydration practice of the early South Americans seems to have been largely forgotten in the United States until 1946 when a group of North Dakota potato growers, led by William M. Case, tried the idea there. Cull potatoes were spread on pasture and allowed to freeze and thaw during the winter and spring. Late in the spring, livestock were let out to pasture to eat the dried potatoes. Both dairy and beef cattle did well in the North Dakota demonstration, with dried potatoes supplying an important part of their rations. The grass stand where the potatoes had been placed improved noticeably as the result of nutrients that had drained onto the soil.

Despite the facts that natural freeze drying[4] of potatoes had been

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[4]The terms "freeze drying" and "freeze dried" as used in this paper refer, respectively, to a method of dehydrating potatoes by alternately freezing and thawing them, and to the resulting product.

practiced for several centuries in South America and in recent times has been demonstrated to be successful in northern North Dakota — where winters are severe, humidity low, and annual precipitation averages only about 20 inches — there is still a need for more information. Of particular importance are such questions as the following: What quantities of the various nutrients are lost from the tubers during freeze dehydration? What is the nature of freeze and thaw dehydration? What are the most feasible conditions for carrying out the natural freeze dehydration of potatoes?

Hence, the Eastern Utilization Research Branch in cooperation with the Maine Agricultural Experiment Station initiated a series of trials at Presque Isle, Maine, in February 1950 which continued until the summer of 1952. Data were obtained on the optimum method of exposing the potatoes and certain observations made on the mechanism of freeze drying and on the nutrient loss.

*Feeding of Freeze-Dried Potatoes*

Although we have not been directly connected with controlled experiments in the feeding of freeze-dried potatoes, all available evidence points to the conclusion that the product is palatable to livestock and without any accompanying bad effects. Following the initiation of our experiments in Maine, several potato growers there conducted satisfactory demonstrations. One grower spread five carloads of potatoes on grassland near Presque Isle, Maine, in February 1950. The partially-dried product was fed successfully the following spring to beef and dairy cattle. (3) The same grower continued trials the following year, this time feeding the product to swine. Another grower near Presque Isle experienced favorable results in feeding freeze-dried potatoes; in the fall of 1951, he put out 30,000 bushels of culls for conversion to dry feed.

More recently, controlled experiments in feeding freeze-dried potatoes have been conducted by T. M. McCall, Superintendent of the Northwest School and Experiment Station, University of Minnesota, at Crookston, Minnesota. (2) McCall and associates observed that steers ate the field-dried potatoes readily and that grass growth was greater where the potatoes had been spread. Homer D. Fausch of the Northwest School and Experiment Station has summarized the results of recent potato feeding trials in Minnesota. (1) In two out of three trials conducted with freeze-dried potatoes in 1951, 1953, and 1954, definitely better weight gains were obtained on the lot of steers fed on potatoes plus pasture than on the control lot fed on pasture alone.

*Experiments at Presque Isle, Maine*

On February 1, 1950, potatoes were placed in the open at Aroostook Farm of the Maine Agricultural Experiment Station under several sets of conditions. Some were spread in layers 4, 8, and 12 inches deep on the ground, and others were placed in well-ventilated structures above ground. One of these structures was cylindrical, about eight feet in diameter and four feet high. It was constructed of snow fence reinforced with wire. The cylinder was mounted on a base 1½ feet above the ground and fitted with a slatted bottom to permit drainage and aeration. An inner cylinder about two feet in diameter was fixed at the center

and left unfilled to facilitate passage of air currents. The annular space between the outer and inner walls of this structure was filled with potatoes and left open at the top. Another structure was horizontal and rectangular, with dimensions 16′ x 4′, and situated 1½ feet above the ground. Potatoes were placed in this structure in 4′ x 4′ areas and at depths of 2″, 4″, 8″ and 12″, with the top left uncovered.

The potatoes froze soon after being placed in the open and did not thaw to any extent for nearly eight weeks. Figures 1, 2, and 3 illustrate how the potatoes were spread and how they shrank during freeze drying. By mid-April, the tubers had shrunk approximately 50 per cent of their original volume. Those in thin layers and on top of thicker layers were soft and had an odor similar to silage. Potatoes lying underneath in the thick layers were largely unfrozen at this time. Additional potatoes were spread in April to see if mild, spring freezes would bring about dehydration. This however, was unsuccessful.

In mid-June, the potatoes had shrunk to approximately one-third of their original volume. No decay was present. It is believed that freeze-dried potatoes are preserved by a fermentation, the products of which inhibit microbial activity that would destroy the tissue. Examination indicated the presence of acid-forming bacteria and of higher acid concentration than ordinarily found in potatoes. The June examination disclosed that tubers in thin layers (two and four inches thick) were firm, but those in 8- and 12-inch layers were soft beneath the surface. Tubers underneath the outer layer in the cylindrical crib were soft, having the consistency of potato silage.

FIGURE 1.—Experimental lots of potatoes spread during winter at 12-, 8-, and 4-inch depths on racks and on the ground. Before freezing and thawing. (Photograph by H. S. Cunningham, Long Island Vegetable Research Farm, Riverhead, N. Y.)

FIGURE 2.—Potatoes in early spring, partially dried by freezing and thawing. Note shriveling.

Precipitation, in inches, was as follows at Presque Isle from February 1 until observations were stopped in the middle of June: February, 1¾; March, 2¼; April, 2½; May, 1; and June, 2 inches.

*Nutrient Losses in the Field Experiments*

Losses in total solids and in various nutrients were ascertained by measuring weight losses that occurred during exposure of the potatoes and by determinations of moisture and of other constituents. Losses of sugars, nitrogen compounds, inorganic compounds (as gauged indirectly by ash determinations), and crude fiber were nearly the same for potatoes stored in the open racks at 4-, 8-, and 12-inch thicknesses. These determinations were made by methods of the Association of Official Agricultural Chemists. (4) Total loss of these substances was 81-82 per cent. No determinations of pectin, organic acids, fat, and minor constituents were made. The starch loss in the 4-inch layer of potatoes was much less than in the 8- and 12-inch layers. Because of this differential in starch loss, loss of total solids during freeze drying was only 28 per cent in the 4-inch layer as compared to 38 per cent in the 8- and 12-inch layers.

FIGURE 3.—Potatoes reduced to one-third their original volume after freezing and thawing during winter and spring.

Data on nutrient losses that occurred during natural freeze drying of potatoes in a 4-inch layer are presented in table 1.

It is seen that nearly all the sugars disappeared from the potatoes and most of the nitrogenous and inorganic compounds. About one-third of the crude fiber and 8 per cent of the starch disappeared.

TABLE 1.—*Nutrient losses during natural freeze drying of potatoes.*[1]

| | 100 Lbs. Potatoes Potatoes, Lbs. | 29.5 Lbs. Product[3] Product,[3] Lbs. | Loss Per cent |
|---|---|---|---|
| Total Solids | 18.0 | 13.0 | 28 |
| Starch | 12.6 | 11.6 | 8 |
| N Compounds[2] | 2.5 | 0.4 | 84 |
| Sugars | 1.30 | 0.04 | 97 |
| Ash | 1.13 | 0.25 | 78 |
| Crude Fiber | 0.47 | 0.31 | 34 |

[1]Potatoes in 4-inch layer in open, ventilated rack above ground. At Presque Isle, Maine, February 7 to June 15, 1950.
[2]Total Nitrogen X 6.25.
[3]56 per cent Moisture.

Undoubtedly much of the nutrient substances that disappear from the potatoes during freeze drying are lost by juice leakage. Some of the nutrient material is lost by liberation of full-strength juice from the potatoes, whereas additional quantities are leached from the tubers during rains and thaws following rains. As previously mentioned, a good part of the juice is evidently utilized as fertilizer by grass if the tubers are spread on pasture. The fraction of the potato nutrients converted to volatile compounds by fermentation, however, is lost for all practical purposes.

It will be noted that the product of natural freeze drying, the composition of which is given in table 1, contained 56 per cent moisture. Even at this relatively high moisture content, the product appeared fairly stable when kept in the open grass under conditions prevailing in the summer in northern Maine. But if freeze-dried potatoes of that moisture range are piled up or confined in a container from which heat cannot readily escape, they will undergo rapid and extensive fermentation.

It is apparent that potatoes dried by freezing and thawing must be dehydrated to approximately 20 per cent moisture content to obtain storage stability.

A new lot of potatoes was spread in the open in November 1950 at Aroostook Farm. These potatoes were placed six to eight inches deep on asphalt felt that covered the ground. Upon examination in June 1951, the tubers were found to be partially dehydrated and free from decay. Their moisture content was estimated to be about 50 per cent at that time. Since no animals were available at Aroostook Farm for experimental feeding, it was planned to ship the product to the principal unit of the Experiment Station at Orono where the Department of Animal Industry is located. Although the partially-dehydrated potatoes were left out throughout the summer of 1951, which was unusually wet at Presque Isle, the product did not become sufficiently dry to permit packaging for shipment. It was then decided to leave the product exposed until spring 1952. Following this year and one-half exposure, it was found that extensive nutrient losses caused by juice leakage and fermentation had left very little of the potatoes except the skin. Therefore, it was concluded that is it not practicable to dry potatoes to stable form (20 per cent moisture or less) by natural conditions in northern Maine.

Dehydration of potatoes by alternate freezing and thawing was also carried out in the laboratory. Although controlled conditions are much different from natural conditions during winter and spring, an advantage was gained in that progressive dehydration could be followed over a series of cycles of freezing and thawing in a relatively short time. In the laboratory, the transformation between the frozen and thawed states was much more rapid than in the outdoors and the potatoes at all times were in a sheltered, relatively dry atmosphere.

The potatoes used in the laboratory freeze drying experiment were of relatively low solids content and all within the 1.045 to 1.055 specific gravity range. They were placed in two wire baskets holding about 30 pounds each. Samples were removed from only one of the baskets so that accumulated weight loss data could be obtained from the other. Results are given in table 2.

Much more juice was lost during the first than in subsequent cycles of freezing and thawing. Weight loss was slight while the potatoes

TABLE 2.—*Progressive weight loss during laboratory dehydration of potatoes*[1] *by alternate freezing and thawing.*[2]

| Cycle Number | Weight Loss, of Original |
|---|---|
| | Per cent |
| 1 | 22.6 |
| 2 | 5.2 |
| 3 | 3.1 |
| 4 | 3.2 |
| 5 | 2.8 |
| 7 | 1.2 |

[1]Original moisture content, 84.4 per cent. Total weight loss after 9 cycles of freezing and thawing plus continuous drying at room temperature, 83 per cent. Final moisture content 18.4 per cent.
[2]In freezer 0°F. overnight, followed by exposure to room temperatu e during the day to complete cycle.

were in the frozen state. For example, in the first cycle, the tubers lost 0.9 per cent of their original weight (presumably, mainly by sublimation of ice) during the freezing phase and 21.7 per cent during thawing. There was a 45 per cent decrease in weight during nine cycles of freezing and thawing, taking place over a period of three weeks. Following this, the potatoes were left out at room temperature for five weeks. The loss during this final treatment, amounting to 38 per cent of the original weight, was by evaporation only, since no more juice escaped.

The data in table 3 show the nutrient losses that occurred during freeze dehydration in the laboratory. Losses of total solids and non-starch solids were almost one-third of those experienced in field dehydration. Loss of starch was nil. Apparently there was much less fermentation of nutrients under laboratory conditions.

TABLE 3.—*Nutrient losses during laboratory freeze-drying*[1] *of potatoes.*

| | 100 Lbs. Potatoes Potatoes, Lbs. | 17.0 Lbs. Product[2] Product,[2] Lbs. | Loss Per cent |
|---|---|---|---|
| Total Solids | 15.6 | 13.9 | 11 |
| Starch | 10.9 | 11.1 | — |
| N Compounds[3] | 2.12 | 1.17 | 45 |
| Sugars | 0.13 | 0.01 | 92 |
| Ash | 0.96 | 0.49 | 49 |
| Crude Fiber | 0.53 | 0.53 | 0 |

[1]Nine cycles, over period 21 days, of freezing at 0°F, followed by thawing at 75°F. After this, potatoes allowed to dry at 75°F. for 35 days.
[2]18.4 per cent moisture.
[3]Total N X 6.25.

### *Microscopical Examinations of Tubers*

Microscopical techniques were used in the search for an explanation of the mechanism of juice leakage caused by freezing and thawing and of the low starch loss in the presence of high losses of other nutrients. Samples of potato tissue were studied under a dissecting microscopic,

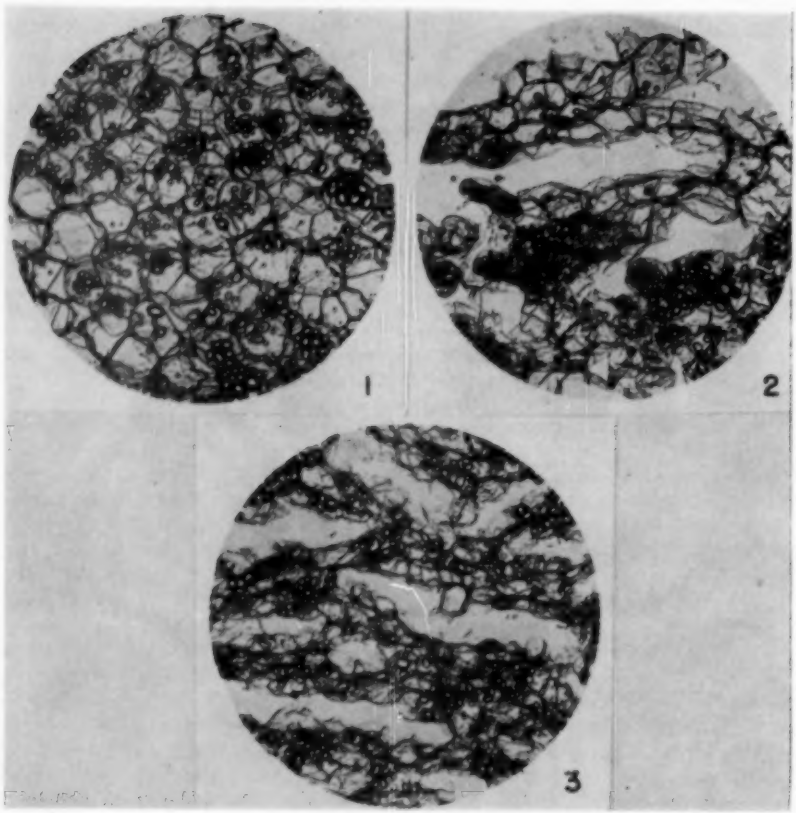


FIGURE 4.—Tissue changes during freezing and thawing of raw potato. Sections 120 microns thick from pith region. Magnification 52X. 1. Untreated potato. 2. First thaw. 3. Third thaw.

and observations made on the cells and tissues as they were subjected to tension and pressure. Observations were made on different regions of the tubers, under different conditions of illumination and at various magnifications. Sections 120 microns thick were prepared from the pith region with the freezing microtome. These were stained and used for making the photomicrographs shown in figure 4.

The following tentative conclusion was made. When a potato is frozen, its tissues expand. For several reasons, among which is the fact that the tissues are not homogeneous throughout their volume with respect to water content and osmotic pressure of cell sap, tissue expansion is greater or more rapid in some regions than in others. Because the tissues contain very little intercellular air which might accommodate or cushion the different rates of expansion, the stresses are transferred directly to the cell walls and intercellular cement. In numerous regions the intercellular

cement gives way and groups of cells are sheared from other groups. For the most part no cells or cell walls are broken, and the starch remains within the cells.

When thawing occurs, sap diffuses from the cells, since the differential permeability of the cell protoplasmic membrane is destroyed by freezing. The cells lose their turgor and the tissues become flaccid. The sap moves into the spaces formed by the shearing apart of cell clusters. This results in a continuous network of channels filled with cell sap. Where the network contacts permeable regions of the potato skin, such as occur in the vicinity of eyes, lenticels, and bruised areas, sap is lost and the tissues contract.

The major damage to tissue structure occurs during the first freeze. Subsequent thawing and freezing treatments apparently cause no more rifts in the tissues, but merely bring about a contraction of those already present. In regions where the intercellular cement is not fractured, the cement remains adequately strong, as is evidenced by the high coherence of tissues.

Photomicrographs given in figure 4 illustrate the progressive changes in tissue that occur during the freezing and thawing of raw potatoes. In the original unfrozen tuber (Figure 4.1.), the cells are tightly stuck together and the tissue is coherent. There is almost no intercellular air. Since the section on the average is about one cell thick, many cells not in the proper plane have been cut open and have thereby lost their starch granules.

After the first freeze (Figure 4.2), the separation of cell clusters and development of channels in the tissue is evident. It is clear that very few cells break, since the cell contours bordering the channels are smooth and the uncut cells contain their original amount of starch granules. This point is corroborated by micro-dissection studies on whole, uncut tissues. After the third thaw (Figure 4.3), a pronounced shrinkage of the tissues and channels is evident. The spatial relationship between the channels and cells, however, is not much different from that in tubers frozen only once.

### *Fermentation Raw Material*

Although it is envisioned that the principal use of freeze-dried potatoes lies in feed, utilization as raw material for fermentations has also been considered. William M. Case, while Executive Secretary of the Red River Valley Potato Growers' Association, suggested that this product be evaluated in alcoholic fermentation. A trial was carried out using field-dried potatoes from the Maine experiment (Table 1), which had been further dehydrated by storing inside. At the time these potatoes were evaluated in alcoholic fermentation at the Northern Utilization Research Branch, they had the following composition in percentages: Moisture, 13.9; starch, 76.6; nitrogen compounds, 2.9; crude fiber, 2.1; ash, 1.8; total sugars, 0.3. A yield of 4.95 proof-gallons of alcohol was obtained per 56 pounds "mash bill" with malt conversion and 5.30 proof-gallons with *A. niger* NRRL 337 (Fungal amylase) conversion. Corn of moisture content comparable to the dehydrated potatoes yields about 5.6 proof-gallons of alcohol per bushel (56 lbs.). Hence, the yield of alcohol from field-dehydrated potatoes was considered rather satisfactory.

*Long Island Experiments*

Cooperative trials in freeze dehydration between the Eastern Utilization Research Branch and the Long Island Vegetable Research Farm of Cornell Agricultural Experiment Station were conducted in 1950 at Riverhead, New York. Potatoes were exposed in various ways in late February and left out until mid-summer. Some of the tubers were spread on uncovered ground, others on asphalt felt, whereas the remainder of the tubers were suspended on open racks 10 inches above the ground in 4-, 8-, and 12-inch layers. At least four severe freezes occurred before spring, and considerable juice was liberated from the potatoes. The moisture content had been reduced from an original 83 per cent to as low as 43 per cent in one lot by late July. Lowest moisture content was attained with the 4-inch layer on the ground. Total precipitation was about 15½ inches during the five months over which observations were made.

Although the potatoes spread at Riverhead did not decay, the tubers fermented badly in the late spring as they lay on open sand, exposed to the hot sun. This excessive fermentation, with accompanying heavy loss of nutrients, was much more severe than experienced in northern Maine grassland. Thus, it appears questionable that freeze drying of potatoes would be feasible on Long Island.

*Summary and Conclusions*

Natural freeze drying of potatoes, when properly carried out, seems practicable in northern areas for converting cull potatoes into a partially stable feed and consequently extend the potato feeding period into late spring and early summer. Potatoes on open racks lost 30-40 per cent of their total solids during this process. Most of the solids lost from the tubers were non-starch substances. Dissolved solids in the juice, upon entering the soil, provide tremendous stimulation to growth of grass. Therefore, apparently much of the solids lost by the tuber are gained by the soil as fertilizer. Laboratory experiments in alternate freezing and thawing resulted in a loss of only approximately 10 per cent total solids. This lower solids loss is thought to be a consequence of the reduced fermentation experienced under laboratory conditions.

Microscopical examination showed that freezing causes groups of cells to shear apart from other groups. After thawing, juice passes through the now permeable cell membranes and escapes through a network of canals between the separated cells. Very little starch is lost in the liberated juice because the potato cells are not ruptured. The greatest loss of juice (23 per cent of original weight of potatoes in a laboratory experiment) occurred during the first thaw. Juice loss decreased during subsequent cycles until only 1 per cent was lost during the seventh cycle.

Spreading potatoes on the ground is apparently more practicable than placing them in a vertical crib or in open, horizontal structures above the ground. Spreading potatoes in layers no more than six to eight inches in depth is better than in deeper layers. The potatoes should be spread in a pasture early enough in the winter to assure exposure to severe freezes. From the experience of livestock men in the Red River Valley and in Maine, apparently the most feasible method of using the field-dehydrated potato feed is to let the animals pick up the tubers from the ground.

Indications are that field-dried potatoes can be used for fermentations as well as for feed. A good yield of alcohol was obtained upon fermenting such potatoes.

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# POTATO VARIETY YIELDS, TOTAL SOLIDS, AND COOKING QUALITY AS AFFECTED BY DATE OF VINE KILLING[1]

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In Maine it is common practice to kill potato vines while they are still green. The grower of certified seed kills the vines the last week in August or the first week in September to avoid the rapid spread of viruses that occurs toward the end of the growing season. The grower of table stock kills the vines early to prevent development of oversize tubers, to permit the skins to toughen, and thus obviate excessive skinning at harvest time, and in blight years to prevent dry rot. These are desirable objectives but they are gained usually at the expense of yield, dry-matter content, and cooking quality. For 3 years, 1950 to 1952, tests were conducted on the Aroostook Farm, Presque Isle, Maine, to determine the effects of date of vine killing on yield, total solids, and quality of chips and french fries.

## Material and Methods

The varieties used in these tests were Irish Cobbler, Sebago, Chippewa, Katahdin, Teton, Mohawk, Kennebec, and Green Mountain. They were planted on May 5 in 1950 and 1951 and on May 6 in 1952. The vines were killed on 4 different dates. A randomized split block, with 4 replications was grown for each of the 4 dates of vine killing. Each single plot consisted of 25 plants spaced 10 inches apart, in rows 34 inches apart. The size of seedpieces ranged from 1.5 to 2.0 ounces. A fertilizer, analyzing 8-16-16 and containing 1 per cent magnesium, was applied at the rate of 1,400 pounds per acre. Regular cultural methods for the area were practiced in growing the crop. The vines on the first block were pulled about August 15, those on the second August 25, and those on the third on or about September 4. The vines on the fourth block were allowed to grow until they were killed by frost or the plants were considered mature enough to harvest. The average date of vine killing on the last block was September 18.

Each year all tubers were harvested on the same date. They were graded to U. S. No. 1 size and weighed. Twenty tubers each weighing about 8 ounces were taken from each 25-hill row to be tested for specific gravity and quality of chips and french fries. The 20-tuber samples were weighed in air and water and the specific gravity was calculated. The specific-gravity data were converted into percentages of solids by the use of a table giving the average percentage of dry matter expected for each specific-gravity reading.

After being weighed in air and water the 20-tuber samples were dried and placed in storage at a controlled temperature of 40°F. After 6 to 8 weeks in this storage the potatoes to be made into chips and french fries were reconditioned at a temperature of 60°F. for 35 days or more.

For chips 2 center slices slightly less than ¼ inch thick were cut from each of 5 tubers. The 10 slices were rinsed with water to remove excess starch, blotted dry with paper towels, and cooked in pure vegetable oil

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(Primex) at a temperature ranging from 335° to 345° F. They were removed from the cooked when bubbling stopped.

For french fries two ½-inch square cores were taken from the center of each of 5 tubers. The 10 pieces were fried in Primex for 4½ minutes at a temperature ranging from 375° to 385°F. A 2-tray deep-fat cooker with thermostatic controls was used for cooking both chips and french fries.

The same 2 men judged the chips and french fries in all tests. They used the classifications employed by processors in Caribou, Maine. The chips and french fries were grouped for color in 7 classes, ranging from class 1 for those with a very deep brown burnt appearance to class 7 for those with a very light tan almost white color. The texture of the french fries was judged by applying pressure with the index finger. The soggiest pieces were grouped in class 1, intermediate in class 2, and the firmest, in class 3.

## Yields

The 8 varieties in the test differed in season of maturity. It might be assumed that the yield of an early variety, such as Irish Cobbler, would be higher on the first date of vine killing than those of any of the late varieties. It is interesting to note that the late-maturing variety Kennebec produced 404 bushels per acre compared with 339 for Irish Cobbler, a difference of 65 bushels on the first date of vine killing, August 15. On that date, Chippewa, Teton, and Mohawk were in the same class as Irish Cobbler so far as yield was concerned, but Sebago, Katahdin, and Green Mountain were significantly lower in yield than the early-maturing Irish Cobbler. On September 18, all 7 late varieties significantly outyielded Irish Cobbler (Table 1).

The mean yield of Irish Cobbler for the 3-year period increased 45.1 per cent from August 15 to September 18. The corresponding increase for Kennebec was 66.6 per cent and for Green Mountain 123.5 per cent. The increases for the other 5 varieties ranged from 73.6 per cent for Chippewa to 92.5 per cent for Mohawk. The increases varied somewhat with the season. In 1950 the mean yield for all varieties increased 90.0 per cent; in 1951, 70.2 per cent; and in 1952, 80.8 per cent. The mean for all varieties for the 3-year period increased from 326 bushels per acre on August 15 to 584 on September 18, or 79.1 per cent.

These data indicate the loss in yield that can be expected by the grower of certified seed who kills the vines about the middle of August to avoid heavy infections with viruses that usually occur toward the end of the growing season. However, growers of table stock do not ordinarily kill the vines until the last week in August or later. The Irish Cobbler increased less than 10 per cent from August 25 to September 18, but the other varieties increased from 32.2 per cent for Kennebec to 47.5 per cent for Mohawk. In 1950 the mean yields for all varieties were 397 bushels per acre on August 25 and 553 on September 18, an increase of 39.3 per cent. In 1951 the corresponding means were 527 and 691, an increase of 31.1 per cent, and in 1952 the means were 381 and 508, an increase of 33.3 per cent. The mean for the 8 varieties for all tests combined were 435 bushels per acre for August 25 and 584 for September 18, an increase of 149 bushels, or 34.3 per cent. This represents the loss that can be expected if the vines are killed about August 25.

TABLE 1.—*Yield data obtained from 8 varieties of potato at 4 dates of vine killing, Presque Isle, Maine, 1950, 1951, and 1952.*

| Variety and Means | Mean Dates of Vine Killing 3-year Means | | | | | Increase Aug. 15 to Sept. 18 | Increase Aug. 25 to Sept. 18 | Increase Sept. 4 to Sept. 18 |
|---|---|---|---|---|---|---|---|---|
| | Aug. 15 Yield per A. | Aug. 25 Yield per A. | Sept. 4 Yield per A. | Sept. 18 Yield per A. | All Tests Yield per A. | | | |
| | Bu.[1] | Bu.[1] | Bu.[1] | Bu.[1] | Bu.[2] | Pct. | Pct. | Pct. |
| Irish Cobbler | 339 | 449 | 468 | 492 | 437 | 45.1 | 9.6 | 5.1 |
| Sebago | 293 | 380 | 478 | 555 | 426 | 89.4 | 46.1 | 16.1 |
| Chippewa | 333 | 428 | 529 | 578 | 467 | 73.6 | 35.0 | 9.3 |
| Katahdin | 297 | 391 | 488 | 539 | 429 | 81.5 | 37.9 | 10.5 |
| Teton | 330 | 443 | 542 | 594 | 477 | 80.0 | 34.1 | 9.6 |
| Mohawk | 305 | 398 | 509 | 587 | 450 | 92.5 | 47.5 | 15.3 |
| Kennebec | 404 | 509 | 578 | 673 | 541 | 66.6 | 32.2 | 16.4 |
| Green Mountain | 293 | 483 | 590 | 655 | 505 | 123.5 | 35.6 | 11.0 |
| Mean All Varieties | | | | | | | | |
| 1950[3] | 291 | 397 | 485 | 553 | 432 | 90.0 | 39.3 | 14.0 |
| 1951[3] | 406 | 527 | 622 | 691 | 562 | 70.2 | 31.1 | 11.1 |
| 1952[3] | 281 | 381 | 462 | 508 | 408 | 80.8 | 33.3 | 10.0 |
| 3 years[4] | 326 | 435 | 523 | 584 | 467 | 79.1 | 34.3 | 11.7 |

[1]L.S.D. at 1 per cent level between means of varieties for each date of vine killing is 42.8 bushels.
[2]L.S.D. at 1 per cent level between means of varieties all tests is 21.4 bushels.
[3]L.S.D. at 1 per cent level betwene dates for any one year is 37.0 bushels.
[4]L.S.D. at 1 per cent level between dates for mean of 3 years is 32.6 bushels.

Killing the vines 14 days before they matured or were killed by frost resulted in significant losses in yield in all varieties except Irish Cobbler. Chippewa, Katahdin, and Teton revealed increases in yield that were significant at the 5 per cent level, and Sebago, Mohawk, Kennebec, and Green Mountain showed highly significant increases from September 4 to 18. The means for all varieties for these 2 dates for 3 years were 523 and 584, a difference of 61 bushels per acre, or about 11.7 per cent. This is a highly significant difference.

## Total Solids Content

It is generally believed that total solids content of potatoes increases as the plants approach maturity. This is probably true in the early stages of tuber development but may or may not be true during the last 4 weeks of the life of the plant. Much depends on the season, as can be seen from the data in table 2.

In 1950 in Maine a warm dry period occurred in May, soon after the potatoes for these tests were planted. This warm weather caused the potato plants to emerge quickly and grow rapidly during the early part of the season. The total solids content reached a maximum on August 15, about 4 weeks before they were harvested. On that date the mean for the 8 varieties was 19.9 per cent and on September 18, 19.6 per cent. The difference is not significant.

The 1951 season was characterized by a late cool spring, followed by cool rainy weather during much of the summer. Although the test plots were planted about the same date as in 1950 they did not get such an early start. Consequently, the dry-matter content did not reach a maximum on August 15 but was comparatively low at that date. It increased gradually from 17.6 per cent on August 15 to 18.7 per cent on September 18, a highly significant increase.

The 1952 season was cool and wet at the time of planting and the plants in the test plots did not get such a good start as they did in 1950. During the latter part of July and the greater part of August the weather was hot and dry. The mean dry-matter content for all varieties on August 15, 1952, was the lowest during any of the 3 years. On August 15 it was 16.7 per cent but it increased to 18.2 per cent by August 25, and 19.7 per cent by September 4; and by September 18 it was 18.9 per cent. It is difficult to account for the difference between the dry matter for September 4 and that for September 18. Evidently an increase in yield between these two dates occurred without a corresponding increase in the percentage of total solids.

The data for each of the 3 years indicate that in 1950 there was no loss in dry-matter content resulting from early vine killing, but in 1951 and 1952 significant losses in percentage of total solids were sustained when the vines were killed as early as August 15. The differences between the percentages for August 25 and September 18 were not significant.

The mean of all varieties for the 3-year period was 18.1 per cent total solids when the vines were killed on August 15; 18.6 per cent on August 25; 19.3 per cent on September 4; and 19.1 per cent on September 18. The differences between the percentages for the first 2 dates and those for the last 2 were highly significant. Although seasons differ and the

TABLE 2.—*Percentages of total solids found in 8 varieties of potato at 4 dates of vine killing, Presque Isle, Maine, 1950, 1951, and 1952.*

| Variety and Means | Mean Dates of Vine Killing 3-year Means | | | | | Increase Solids Aug. 15 to Sept. 18 | Increase Solids Aug. 25 to Sept. 18 | Increase Solids Sept. 4 to Sept. 18 |
|---|---|---|---|---|---|---|---|---|
| | Aug. 15 Solids | Aug. 25 Solids | Sept. 4 Solids | Sept. 18 Solids | All Tests Mean Solids | | | |
| | Pct.[1] | Pct.[1] | Pct.[1] | Pct.[1] | Pct.[2] | Pct. | Pct. | Pct. |
| Irish Cobbler | 19.6 | 19.7 | 20.0 | 19.8 | 19.8 | 1.0 | 0.5 | –1.0 |
| Sebago | 16.2 | 17.2 | 18.3 | 18.5 | 17.6 | 14.2 | 7.6 | 1.1 |
| Chippewa | 16.6 | 16.9 | 17.6 | 17.0 | 17.0 | 2.4 | .6 | –3.5 |
| Katahdin | 17.8 | 18.2 | 18.7 | 18.7 | 18.4 | 5.1 | 2.7 | .0 |
| Teton | 18.7 | 19.1 | 19.0 | 18.7 | 18.9 | .0 | –2.1 | –1.6 |
| Mohawk | 18.3 | 19.4 | 20.5 | 20.5 | 19.7 | 12.0 | 5.7 | .0 |
| Kennebec | 18.0 | 18.8 | 19.1 | 18.7 | 18.7 | 3.9 | –.5 | –2.1 |
| Green Mountain | 19.2 | 19.8 | 20.8 | 20.3 | 20.0 | 5.7 | 2.5 | –2.5 |
| Mean All Varieties | | | | | | | | |
| 1950[3] | 19.9 | 19.6 | 19.7 | 19.6 | 19.7 | 1.5 | .0 | –.5 |
| 1951[3] | 17.6 | 18.0 | 18.4 | 18.7 | 18.2 | 6.3 | 3.9 | 1.6 |
| 1952[3] | 16.7 | 18.2 | 19.7 | 18.9 | 18.4 | 13.2 | 3.8 | –4.2 |
| 3 years[4] | 18.1 | 18.6 | 19.3 | 19.1 | 18.8 | 5.5 | 2.7 | –1.0 |

[1]L.S.D. at 1 per cent level between means of varieties for each date of vine killing, 0.56 per cent.
[2]L.S.D. at 1 per cent level between means of varieties all tests, 0.28 per cent.
[3]L.S.D. at 1 per cent level between dates for any one year, 0.81 per cent.
[4]L.S.D. at 1 per cent level between dates for mean of 3 years, 0.47 per cent.

percentages of total solids vary with the seasons, it is evident that over a period of years significant losses in dry-matter content are sustained if the vines are killed early.

### Color of Chips

The chips were rated in 7 classes according to the degree of browning. A rating of 7 signified a light tan, almost white color, and the lower the number the greater the amount and intensity of the brown color. The chips in class 1 were very dark brown with a burnt appearance. Such chips would have no commercial value. Chips in classes 4 to 7 are usually preferred by the trade.

The chips of all varieties except Irish Cobbler improved in color from August 15 to September 18. The early maturity of the Irish Cobbler is reflected in these results. The other varieties matured later than the Irish Cobbler, and the color of their chips improved as they approached maturity. The improvement in the color of the chips made from the late-maturing varieties was highly significant when the data for the first and second dates of vine killing were compared with those of the fourth as revealed in table 3.

The chips of Irish Cobbler and Kennebec, which graded higher than class 4 when the vines were killed on August 15, would be acceptable to the trade at any of the dates of vine killing. The chips made from Katahdin tubers for the first 3 dates of vine killing were too dark in color to be preferred by the trade, but when the plants of this variety were allowed to mature or be killed by frost its chips graded higher than 4. The color of the chips made from Green Mountain for all dates of vine killing graded too low to be acceptable to the trade.

The seasonal differences are indicated by the means of all the varieties for each of the 3 years. In 1950 there were no significant differences in the data for any of the 4 dates of vine killing. In 1951, and again in 1952, highly significant differences were found. When the means for all the varieties for the 3-year period are considered there is no significant difference between the first and second dates of vine killing, but there are highly significant differences between the first 2 and the last 2 dates.

The color of chips varies with the variety and with the maturity of the potatoes. Chips with satisfactory color can be made from some varieties when they are relatively immature, but the color of chips made from most varieties improves as the tubers reach maturity.

### Color of French Fries

The same criteria were used in judging the color of french fries as were used in classifying the color of the chips. French fries in color classes 5 to 7 are preferred by the trade.

The color of french fries made from Kennebec averaged 5 for a mean of 4 dates of vine killing for three years. The mean 4.8 and 4.9 for August 15 and August 25, respectively, were not significantly different from 5.0 and 5.2, the means for September 4 and September 18. It is evident that french fries with an acceptable color were made from the tubers of Kennebec in any stage of maturity reached from August 15 to September 18. Irish Cobbler was a close second, and no significant differences were

TABLE 3.—*Color of chips made from 8 varieties of potato at 4 dates of vine killing, Presque Isle, Maine, 1950, 1951, and 1952.*

| Variety and Means | Mean Dates of Vine Killing 3-year Means | | | | | Color Improvement | | |
|---|---|---|---|---|---|---|---|---|
| | Aug. 15 Color Class[1] | Aug. 25 Color Class[1] | Sept. 4 Color Class[1] | Sept. 18 Color Class[1] | All Tests Mean Color Class[2] | Aug 15. to Sept. 18 | Aug. 25 to Sept. 18 | Sept. 4 to Sept. 18 |
| | No. | No. | No. | No. | No. | Pct. | Pct. | Pct. |
| Irish Cobbler | 4.5 | 4.0 | 4.7 | 4.4 | 4.4 | –2.3 | 10.0 | –6.8 |
| Sebago | 3.3 | 3.4 | 3.7 | 3.8 | 3.6 | 15.2 | 11.8 | 2.7 |
| Chippewa | 2.9 | 2.9 | 3.6 | 3.7 | 3.3 | 27.6 | 27.6 | 2.8 |
| Katahdin | 2.9 | 2.8 | 3.8 | 4.2 | 3.4 | 44.8 | 50.0 | 10.5 |
| Teton | 3.2 | 3.3 | 3.8 | 3.6 | 3.5 | 12.5 | 9.1 | –5.6 |
| Mohawk | 2.3 | 2.6 | 2.8 | 3.6 | 2.8 | 56.5 | 38.5 | 28.6 |
| Kennebec | 4.1 | 4.1 | 4.6 | 5.3 | 4.5 | 29.3 | 29.3 | 15.2 |
| Green Mountain | 1.5 | 1.4 | 2.0 | 1.9 | 1.7 | 26.7 | 35.7 | –5.3 |
| Mean All Varieties | | | | | | | | |
| 1950[3] | 3.5 | 3.1 | 3.0 | 3.3 | 3.2 | –6.1 | 6.5 | 10.0 |
| 1951[3] | 2.1 | 2.4 | 2.8 | 3.3 | 2.7 | 57.1 | 37.5 | 17.9 |
| 1952[3] | 3.3 | 3.7 | 5.0 | 4.8 | 4.2 | 45.5 | 29.7 | –4.1 |
| 3 years[4] | 3.0 | 3.1 | 3.6 | 3.8 | 3.4 | 26.7 | 22.6 | 5.6 |

[1]L.S.D. at 1 per cent level between means of varieties for each date of vine killing, 0.62.
[2]L.S.D. at 1 per cent level between means of varieties all tests, 0.31.
[3]L.S.D. at 1 per cent level between dates for any one year, 0.64.
[4]L.S.D. at 1 per cent level between dates for mean of 3 years, 0.37.

TABLE 4.—*Mean color of french fries made from 8 varieties of potato at 4 dates of vine killing, Presque Isle, Maine, 1950, 1951, 1952.*

| Variety and Means | Mean Dates of Vine Killing 3-year Means | | | | | Color Improvement | | |
|---|---|---|---|---|---|---|---|---|
| | Aug. 15 Color Class[1] | Aug. 25 Color Class[1] | Sept. 4 Color Class[1] | Sept. 18 Color Class[1] | All Tests Mean Color Class[2] | Aug. 15 to Sept. 18 | Aug. 25 to Sept. 18 | Sept. 4 to Sept. 18 |
| | No. | No. | No. | No. | No. | Pct. | Pct. | Pct. |
| Irish Cobbler | 4.3 | 4.5 | 4.6 | 4.6 | 4.5 | 7.0 | 2.2 | 0.0 |
| Sebago | 4.0 | 4.0 | 4.0 | 4.2 | 4.0 | 5.0 | 5.0 | 5.0 |
| Chippewa | 3.4 | 3.9 | 4.1 | 4.6 | 4.0 | 35.3 | 17.9 | 12.2 |
| Katahdin | 3.9 | 3.6 | 4.0 | 4.3 | 3.9 | 10.3 | 19.4 | 7.5 |
| Teton | 3.2 | 3.6 | 3.9 | 3.8 | 3.6 | 18.8 | 5.6 | –2.6 |
| Mohawk | 2.7 | 2.7 | 3.5 | 3.6 | 3.1 | 33.3 | 33.3 | 2.9 |
| Kennebec | 4.8 | 4.9 | 5.0 | 5.2 | 5.0 | 8.3 | 6.1 | 4.0 |
| Green Mountain | 1.5 | 1.6 | 2.0 | 2.3 | 1.9 | 53.3 | 18.8 | 15.0 |
| Mean All Varieties | | | | | | | | |
| 1950[3] | 3.8 | 3.6 | 3.2 | 3.6 | 3.6 | –5.6 | .0 | 12.5 |
| 1951[3] | 2.7 | 3.1 | 3.6 | 3.9 | 3.3 | 44.4 | 25.8 | 8.3 |
| 1952[3] | 3.8 | 4.0 | 4.8 | 4.7 | 4.3 | 23.7 | 17.5 | –2.1 |
| 3 years[4] | 3.5 | 3.6 | 3.9 | 4.1 | 3.8 | 17.1 | 13.9 | 5.1 |

[1]L.S.D. at 1 per cent level between means of varieties for each date of vine killing, 0.54.
[2]L.S.D. at 1 per cent level between means of varieties all tests, 0.27.
[3]L.S.D. at 1 per cent level between dates for any one year, 0.53.
[4]L.S.D. at 1 per cent level between dates for mean of 3 years, 0.31.

found between the means for any of the dates of vine killing. The color of the chips made from Green Mountain at any of the dates of vine killing would not be acceptable to the trade as shown in table 4.

Seasonal differences are apparent in the color of the french fries. In 1950, judging from the means of all varieties, there was no improvement in color throughout the tests. However, in 1951 and 1952 the improvement in color from August 15 to September 4 was highly significant.

## Texture of French Fries

Data on texture of french fries were taken for 2 years as you will observe in table 5. The french fries made from Irish Cobbler, Katahdin, Mohawk, Kennebec, and Green Mountain were on the average in No. 3 or highest class in firmness of texture. The other 3 varieties, Chippewa, Sebago, and Teton, rated on the average 2.7, 2.8, 2.9, respectively. The texture of the french fries as not closely associated with date of vine killing or season. There was little or no difference between any 2 of the 4 dates for any of the varieties, and the results for each of the 2 years and the means for both years were very similar.

## Summary

In Maine growers of certified seed potatoes often kill the vines during the last week in August or the first week in September to avoid the rapid spread of virus diseases that may occur toward the end of the growing

Table 5.—*Texture of french fries made from 8 varieties of potatoes at 4 dates of vine killing, Presque Isle, Maine, 1950 and 1951.*

| Variety and Means | Mean Dates of Vine Killing 2-Year Means | | | | 4 Dates Mean Texture Class |
|---|---|---|---|---|---|
| | Aug. 15 Texture Class | Aug. 25 Texture Class | Sept. 4 Texture Class | Sept. 18 Texture Class | |
| | No. | No. | No. | No. | No. |
| Irish Cobbler | 3.0 | 2.9 | 2.9 | 3.0 | 3.0 |
| Sebago | 2.8 | 2.9 | 2.7 | 2.6 | 2.8 |
| Chippewa | 2.7 | 2.8 | 2.6 | 2.8 | 2.7 |
| Katahdin | 3.0 | 2.9 | 3.0 | 3.0 | 3.0 |
| Teton | 2.9 | 2.8 | 2.8 | 2.9 | 2.9 |
| Mohawk | 3.0 | 3.0 | 2.9 | 3.0 | 3.0 |
| Kennebec | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| Green Mountain | 3.0 | 2.9 | 3.0 | 2.9 | 3.0 |
| Mean All Varieties | | | | | |
| 1950 | 2.9 | 2.9 | 2.9 | 2.8 | 2.9 |
| 1951 | 2.9 | 2.9 | 2.8 | 2.9 | 2.9 |
| 2 Years | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 |

season. The grower of table stock kills the vines early to prevent development of over-size tubers, to permit the skins to toughen, and thus obviates excessive skinning at harvest time, and in blight years to prevent dry rot.

Data for 3 years of tests with 8 varieties of potato and 4 dates of vine killing, August 15, August 25, September 4, and September 18, indicate that early vine killing resulted, on the average, in lower yields, lower percentages of total solids, and inferior color of chips and french fries. The texture of the french fries was not affected to a measurable degree. Varietal and seasonal differences were apparent. The early-maturing Irish Cobbler was less affected by early vine killing than most of the late varieties. Kennebec, a late-maturing variety, yielded higher than the Irish Cobbler on August 15 and increased rapidly from that date to the end of the growing season. Green Mountain, another late variety, produced relatively low yields on August 15 but its yields increased rapidly thereafter.

In 1950 the percentage of total solids was about as high on August 15 as it was at any of the other vine-killing dates, but in 1951 and 1952 the dry-matter content of all varieties except Irish Cobbler increased significantly after August 15.

On the first date of vine killing the color of chips from only 2 varieties, Irish Cobbler and Kennebec, was acceptable. The chips made from Katahdin improved in color as the variety approached maturity. The color of the Green Mountain chips was not acceptable at any vine-killing date.

The color of the french fries followed the same pattern in all tests as the color of the chips.

## NEWS AND REVIEWS

# "REPORT ON RESEARCH" PRESENTED AT SUMMER CONFERENCE AT SKYTOP, PA., JUNE 20, 1955

ORA SMITH[1]

We are continuing to emphasize the value of selecting high specific gravity potatoes for chipping. Dr. Al Mercker stated that potatoes from North Carolina this year varied in specific gravity from 1.077 to 1.090. I want to add to this statement that for every car of potatoes of 1.090 specific gravity which you may have purchased, you would obtain about 900 pounds more chips than from each car of 1.077 specific gravity. The only way to be sure of selecting the high specific gravity potatoes is to test the various lots which are available. The instrument best adapted to this process is the potato hydrometer.

We plan to start research this fall using our specific gravity grader for separating lots of potatoes into high and low specific gravity groups. These are to be cooked separately and yields of chips calculated from each 100 pound bag of potatoes. This grader also will be used for floating off hollow heart tubers and potatoes that are partially decayed.

Our field experiments now in progress are aimed at methods of improving quality of potatoes for chip processing. These consist of such factors as irrigation to supplement rainfall, spray applications of nitrogen to the foliage, omission of DDT from the last three fungicide sprays, use of insecticides other than DDT, various methods of killing potato vines and different stages of maturity as obtained by varying date of harvest.

In other experiments we are trying to improve the quality of potatoes for chips, especially for improved color, by spray applications of sequestering and chelating agents made at various times during the growing season.

The research on spray applications of sprout inhibitors to plants in the field also is being continued. We are using maleic hydrazide primarily in this study. Application of Chloro IPC directly to the tubers as they go into storage or by vaporizing the chemical after the potatoes have been placed in storage is being continued. We also are cooperating in the research on irradiation of potatoes for sprout inhibition and the effects on the quality of potatoes for chips.

A study is now in progress on the effects of humidity in storage on the rate and degree of conditioning potatoes for chips.

Further work is in progress on antioxidants. We are testing several new chemicals for their value as antioxidants and are using newer methods of applying some of the older standard antioxidants to chips.

A comprehensive research project of 2 years duration in cooperation with the Eastern Utilization Research Branch, United States Department of Agriculture is just being started. This is for the purpose of determining the relative importance of potato protein and other nitrogenous fractions as factors in causing dark color chips. We hope to find a series of cultural and storage treatments that will result in chemical composition of tubers favorable for processing chips of satisfactory color.

We are conducting a survey of the potato research projects in progress in all the state and federal agricultural experiment stations in

the United States and of the provinces and federal government of Canada. Over 100 letters have been sent to research men and a good response has been obtained. These projects will be listed by states so that you may be aware of the type of potato research in your state and section of the country. The projects also will be listed under various subject matter headings so that you may, in a short time, determine what areas are conducting that type of research. When this survey is completed each member of the Institute will receive a copy.

Five news letters have been sent to each Institute member discussing some timely topic of interest and value to you. I hope you have found them so.

—Reprinted from *Potato Chipper*, AUGUST, 1955

[1]Director of Research, National Potato Chip Institute.

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## USDA SCIENTISTS PROGRESS IN SEARCH FOR BETTER POTATO SPROUT INHIBITOR

Continuing progress toward the development of a superior sprout inhibitor for use on stored potatoes is reported by plant physiologists of the U. S. Department of Agriculture.

Best of several organic chemicals thus far tested by research scientists at USDA's Plant Industry Station, Beltsville, Md., is 3-chloro-isopropyl-N-phenyl carbamate — generally referred to as 3-Cl-IPC. This material proved to be an effective sprout inhibitor on several varieties of potatoes stored at temperatures ranging from 45 to 65 degrees F.

However, commercial potato growers and handlers are cautioned that this likely-appearing material is not yet recommended for their use. It must first be proved that residues of 3-Cl-IPC do not harm the quality of the potatoes or present a hazard to the consumer.

At the lower test-storage temperatures — 45 and 55 degrees — 3-Cl-IPC not only prevented the development of sprouts for more than 8 months, but reduced the tendency of the potatoes to rot. Other chemical sprout inhibitors have generally increased rotting. This material also proved to be effective at a low dosage rate, which may prove to be an important factor in the acceptability of 3-Cl-IPC in terms of residue-tolerance limitations.

In comparative storage trials, conducted for 8 months at 45- and 55-degree temperatures, 3-Cl-IPC allowed no sprout development on four varieties of potatoes — Chippewa, Kennebec, Irish Cobbler, and Katahdin — that had been grown in North Dakota and Maine. Loss in weight due to sprouting on the untreated potatoes stored at 45 degrees amounted to 3.6 per cent; at 55 degrees, 5.1 per cent.

Per cent of rotting was reduced by chemical treatment from 9.9 to 6.6 at 45 degrees; from 8.6 to 5.8 at 55 degrees.

Although momentarily dipping the potatoes in a 0.5 per cent solution of 3-Cl-IPC prevented sprout development at the lower storage temperatures, the chemical provided no effective inhibition at storage temperatures of 70 degrees F. and above.

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